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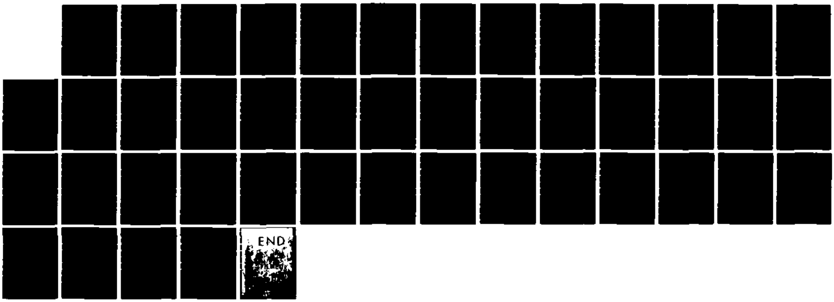

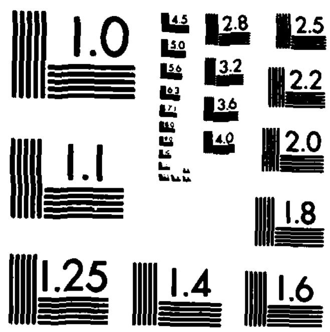

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

PROPERTIES OF WEATHERED UNCOATED AND "RESATURANT"-COATED BITUMINOUS BUILT-UP ROOFING MEMBRANES

June 1983

An Investigation Conducted by
NATIONAL BUREAU OF STANDARDS
Washington, D.C. 20234

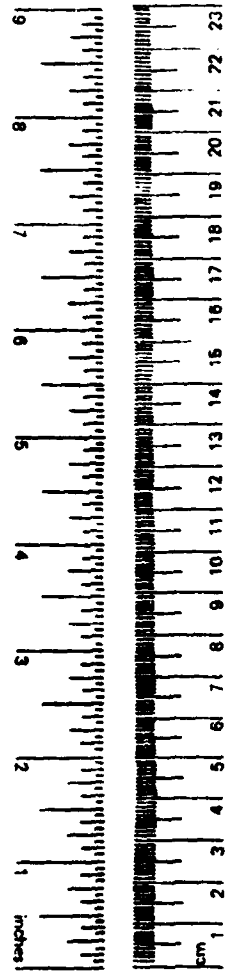
N68305-82-WR-20172

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

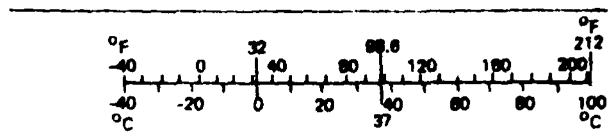
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Bituminous; built-up; coatings; membrane; performance properties; resaturants; roofing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study to compare the performance properties of weathered built-up membranes which had and had not been subjected to an application of "resaturant"-type coatings has been conducted. The membrane samples (asphaltic and coal-tar pitch), which were taken from roofs of buildings, ranged in age from 14 to 26 years. Sections of these roofs had been treated with one of three

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) proprietary "resaturant"-type coatings. The age of coatings ranged from 12 to 29 months. The membrane samples removed from the roofs were visually examined in the laboratory to determine their general condition, the extent of adhesion between plies of felts, the number of plies, and the thicknesses of the interply bitumen. The visual examination indicated that damage to some areas of the top ply of felt of most of the coated coal-tar pitch membrane samples had occurred. The damage was attributed, in part, to removal of the aggregate surfacing prior to "resaturant"-coating application. Membrane properties measured in the laboratory for undamaged test specimens were tensile strength, load-strain modulus, flexural strength, maximum deflection (flexure), coefficient of linear thermal expansion, and thermal shock factor. The results are applicable only to the membranes tested since the number of membranes samples and coatings included in the study were limited. Comparisons of the average values of the properties for uncoated and comparable coated specimens in general showed no significant statistical differences. In addition, no consistent trends were found as to whether or not the average values of the measured properties of the coated specimens were higher or lower than those of comparable uncoated specimens.

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1. INTRODUCTION

The majority of the low-sloped roofs of industrial and commercial buildings in the United States are waterproofed with bituminous built-up roofing membranes. Experience has shown that in many cases a built-up roofing membrane can have a service life of 20 years or more. However, in other cases, its service life is much shorter than anticipated. For example, from the results of a survey on the durability of built-up membranes fabricated with organic or asbestos felts, Cash (1980) indicated that a roofing membrane has no greater than a 50 percent probability of lasting 20 years. The number of early roofing failures, resulting in costly repairs or replacement of built-up membranes, has lead to efforts to prolong membrane service life. One method has been the application of a type of roof coating commonly referred to as a "resaturant".

"Resaturants" have been described by Karolefski (1980) as asphalt or coal-tar pitch materials that are formulated with oils designed to penetrate the bitumen to which they are applied to restore flexibility and performance. Bynoe (1980) prefers the description, "reimpregnating coatings," instead of "resaturants". He has enumerated the intended uses of the coatings as follows: (1) to fill fractures and voids in weathered flood coats to prevent water access to organic felts; (2) to penetrate as far as possible into organic felts to fill voids more completely and provide against water infiltration; and (3) to rejuvenate weathered asphalts by lowering their softening points and raising their penetration indices, so that they can perform more like they did when first applied. Karolefski (1980) pointed out that the effectiveness of "resaturant"-type coatings for revitalizing weathered roofing membranes is a controversial subject and unresolved issue. He indicated that although accepted by many individuals in the roofing industry, there exists a lack of unbiased, scientific evidence supporting the coatings. Viewpoints on the effectiveness of "resaturant"-type coatings applied to weathered built-up membranes have been presented by Williams (1982) and Bynoe (1982). Research results on the effect of "resaturant"-type coatings on the performance properties of weathered built-up membranes have not been reported.

Bynoe (1980, 1982) has reported the results of laboratory tests on the effect of the coatings in lowering the softening points and raising the penetration indices of heat aged bitumens. He also described a radioactive-tracer experiment in which the penetration of "resaturant"-type coatings through the felts of 15-year-old 4-ply coal-tar pitch and asphalt built-up membranes was investigated. The experiment indicated that the percent distribution of radioactivity in the membrane was about as follows: 40-50 percent in the flood coat, 20-25 percent in the top ply of felt, 4-8 percent in the second ply of felt, 0.5-4 percent in the third ply, and 0.2-2 percent in the bottom ply of felt.

2. OBJECTIVE AND SCOPE

The objective of the investigation was to compare some performance properties of bituminous built-up roofing membranes which had and had not been subjected to "resaturant"-type coatings. Weathered samples of uncoated and comparable coated membranes having aggregate surfacing were removed from the roofs of buildings located at a U.S. Government installation in Kentucky. The roofs from which the samples were taken were exposed to essentially the same weather conditions. The membrane samples were visually examined in the laboratory to determine their general condition, the extent of adhesion between plies of felts, the number of plies, and the thicknesses of the interply bitumen.

Laboratory tests were conducted to determine values of membrane performance properties including tensile strength, load-strain modulus, flexural strength, maximum deflection (in flexure), the coefficient of linear thermal expansion, and the thermal shock factor. The results of the laboratory tests for the uncoated and comparable coated membrane samples were compared using statistical and graphical analyses to determine whether significant differences existed between the properties of the uncoated and coated samples. Bitumen properties such as softening point and penetration for the uncoated and coated samples were not measured, since such properties have not been included as membrane performance properties (Mathey and Cullen, 1974; Building Research Advisory Board, 1964).

3. MEMBRANE SAMPLES

Four groups of built-up roofing membrane samples were included in the study (table 1). Each group of samples contained comparable membranes that had and had not been coated with a "resaturant", thus, allowing a direct comparison of the properties of uncoated and coated samples. One group of samples was from a building having an asphalt built-up membrane. The coated specimens from this building had received an asphaltic "resaturant" coating. The other three groups of samples were removed from roofs having coal-tar pitch membranes. In these cases one of two coal-tar pitch "resaturant" coatings had been applied. Before application of the coatings, most of the aggregate surfacing (estimated 70-90 percent) had been removed by either hand or power brooming. For each sample group, the type of membrane, method of its application and age were the same. The three "resaturant"-type coatings included in the study were proprietary and had been applied to the roofs 12 to 29 months before this study was conducted. The composition of the "resaturant"-type coatings was not known.

Twenty roofing membrane samples, 0.6 x 1.2 m (2 x 4 ft), were taken from ten different sections of roofs (table 1) representing five buildings. Table 1 gives the roof groups having comparable samples, the type of bitumen in the membrane, the age of the membrane, and the age of the coating on the membrane. From this table it is seen that roof groups I, III, and IV contained two uncoated and two coated samples. Five of the eight samples in roof group II were coated. The information in table 1 and other information pertaining to the roofs and the application of the coatings were provided by personnel at the facility where the samples were taken.

The membrane samples were taken from well-drained areas of the roofs where the membranes appeared to be in good condition. In most cases, the long dimension of the samples was perpendicular to the direction of felts as applied.

4. LABORATORY OBSERVATIONS

Prior to examination of the membrane samples in the laboratory, the aggregate surfacings were removed carefully to avoid damage to the membrane. It was noted that the aggregate surfacings on the coated specimens were adhered strongly to the top of the membrane. A strip, 0.15 x 1.0 m (6 x 40 in.), from each membrane sample was cooled to -40°C (-40°F) and delaminated to observe the number of plies, lap spacing, adhesion between plies, and bitumen interply thickness. The strips were flexed manually at room temperature prior to delamination and subjectively judged as pliable or brittle. The general condition of the samples was observed at room temperature prior to removal of the strip for delamination. These observations are reported in table 2. The membrane condition was considered to be good, if typical defects such as splits, blisters, surface deterioration, and damage to felts (tears) were not observed, or were seen but limited to a relatively small area (estimated less than 5 percent) of the sample. The membrane samples contained asphalt or coal-tar pitch organic felts which appeared to be similar to the type commonly called "No. 15 asphalt felt."

The membrane samples from roof group I were from a building with a plywood roof deck. These membranes contained four plies (table 2). Two plies were nailed to the deck and two plies were applied in shingle fashion with hot asphalt. These samples were observed to be in good condition and judged to be pliable at room temperature. It was visually estimated that they contained a normal thickness of interply asphalt and had good adhesion between plies.

The coal-tar pitch membrane samples, roof groups II, III, and IV, had in general four plies applied in shingle fashion (table 2). Seven of the 16 samples were observed to contain some areas where the top ply of felt was damaged (tears or areas of missing felt). Nevertheless, these seven membrane samples had adequate undamaged sections from which test specimens were prepared for conducting laboratory tests. The coal-tar pitch samples were considered brittle at room temperature. All of the seven samples described as having damage of the top ply of felt were coated. Some of the damage was attributed to removal of the aggregate surfacing from the roofing by hand or power brooming prior to application of the coating. Two of the nine uncoated coal-tar pitch samples, which were described as being in good condition, showed some damage to relatively small area (estimat‹ less than 5 percent) of the top ply of felt.

Delamination of the membrane strips removed from the coal-tar pitch samples indicated that adhesion between the plies was generally good (table 2). The thickness of the coal-tar pitch between plies for many samples was visually estimated to be thinner than normal. The delaminated strips from sample nos. 5, 6, 7, and 19 showed evidence of minor deterioration of the top ply of felt. One or two small voids in the interply bitumen layers were observed in the case of sample nos. 5, 6, 9, 17, and 19. These voids generally occurred between the bottom ply and second ply from the bottom. Sample no. 8 had a small patch over a split in the membrane. The delaminated strip cut from sample no. 6 had an additional ply of felt over the four shingled plies. This additional ply was not present over the entire surface of the sample removed from the roof.

5. LABORATORY TESTS

Laboratory tests were conducted to determine some performance properties of the uncoated and coated membrane samples including tensile strength, load-strain modulus, flexural strength, maximum deflection from flexural tests, and the coefficient of linear thermal expansion. The tests to determine these properties have been described in the National Bureau of Standards report on preliminary performance criteria for bituminous membrane roofing (Mathey and Cullen, 1974).

In comparing performance properties of the uncoated and comparable coated membrane samples, it was intended to include all mechanical property tests given in this earlier National Bureau of Standards report. However, preliminary laboratory testing indicated that tension fatigue and punching shear tests were not suitable for the weathered coal-tar pitch membrane specimens. For example, the brittle membrane specimens delaminated after relatively few cycles in the tension fatigue test. These brittle membrane specimens attached to fibrous glass insulation substrates underwent large deflections without indentation or puncturing under relatively high load in the punching shear test. On this basis, it was decided not to conduct the fatigue, punching shear, and impact tests.

Test specimens were selected and cut from areas of uncoated and coated membrane samples that were in good condition. The asphalt membrane test specimens, roof group I, contained three plies and the coal-tar pitch test specimens, roof groups II, III, and IV, contained four plies.

The tensile and flexural tests were conducted at 23 and -18°C (73 and 0°F) using specimens having the transverse (cross-machine as manufactured) direction of the membrane felts oriented along the longitudinal axis of the test specimens. The test specimen geometry is given in ASTM Standard D 2523. The same type of specimen was used in tests for determining the coefficient of linear thermal expansion over temperature ranges of -1 to -18°C (30 to 0°F) and -18 to -34°C (0 to -30°F).

For all tests, three specimens were generally tested at each temperature or temperature range. During the tensile tests, the rate of load was 2 mm/min (0.08 in./min). For the flexural tests the specimens were tested over a span of 178 mm (7 in.) and the rate of load was 10 mm/min (0.4 in./min).

Using the results of the laboratory tests the thermal shock factor (TSF) was calculated (Mathey and Cullen, 1974) from the expression:

$$TSF = \frac{P}{M\alpha} \tag{1}$$

where,

P is the tensile strength at -18°C (0°F),

M is the load-strain modulus at -18°C (0°F), and

α is the coefficient of linear thermal expansion for the temperature range -18 to -34°C (0 to -30°F).

6. TEST RESULTS AND STATISTICAL ANALYSIS

6.1 General Considerations

The results of the individual tests for uncoated and coated specimens for each of the four roof groups and for each of the membrane properties at the two test temperatures are plotted in figures 1 to 5. Figure 6 gives calculated values of the thermal shock factor for individual uncoated and coated specimens.

Tables 3-8 present a summary of the statistical analysis of test results of membrane properties for the four roof groups. The number of uncoated and coated specimens and the average property value for the uncoated and coated specimens are given for each roof group for the two test temperatures.

The average values of each membrane property for the uncoated and coated specimens for each roof group at the two test temperatures were compared statistically using the t-test at the 0.05 significance level (see, for example, Natrella, 1966). The last three columns in tables 3-8 give the summary of the statistical analyses. The pooled standard deviation applies to all specimens (uncoated and coated) within a roof group for a given temperature. The significance column notes whether or not there is a statistically significant difference between average values of uncoated and coated specimens within a group for a given temperature. The change in property column indicates whether the average property value of the coated specimens was greater (+) or less (-) than that of the uncoated specimens.

6.2 Tensile Strength

For each roof group for the two temperatures, values of tensile strength of individual uncoated and coated specimens (figure 1) were, in general, in the same range. The scatter in the points was greatest for roof group IV at -18°C (0°F). For each comparable roof group, the average tensile strengths were greater at -18°C (0°F) than at 23°C (73°F). The average tensile strengths of the asphalt specimens (roof group I) were less than the coal-tar pitch specimens (roof group II, III, and IV) for both temperatures. This was attributed in part to the asphalt specimens having 3 plies of felt and the coal-tar pitch specimens containing 4 plies.

In all cases there were no significant differences between the average tensile strengths of the uncoated and coated specimens for the four roof groups at the two temperatures (table 3). Also, there was no consistent trend in whether or not the average values of tensile strength of the coated specimens were higher or lower than those for comparable uncoated specimens.

6.3 Load-Strain Modulus

Figure 2 presents values of load-strain modulus for individual membrane specimens, with five points, as indicated by the arrows at the top of the -18°C (0°F) plot, falling beyond the upper limit of the plot. The load-strain modulus was in general greater at the colder temperature for comparable roof groups. The scatter in the results was considerably greater for roof groups II and IV at -18°C (0°F) than for the other roof groups at both temperatures.

The average load-strain modulus of the asphalt membrane specimens (roof group I) was less than that of the coal-tar pitch membrane specimens (roof groups II, III, and IV) at both temperatures. This result was consistent with the laboratory observation that the asphalt samples were judged to be pliable and the coal-tar pitch samples were judged to be brittle at room temperature (table 2). As given in table 4 the average values of the load-strain modulus of the uncoated and comparable coated specimens were not significantly different. In the case of the coal-tar pitch specimens (roof groups II, III, and IV), average values of the coated specimens were lower than those of the uncoated specimens at 23°C (73°F) and were higher at -18°C (0°F). Conversely, for the asphalt specimens at -18°C (0°F) the coated specimens had a lower average value of load-strain modulus than the uncoated specimens. At 23°C (73°F) the average values were the same.

6.4 Flexural Strength

Flexural strength results for individual membrane samples are given in figure 3. The scatter is the greatest for the specimens in roof groups II and IV at 23°C (73°F). In comparing the flexural strengths at 23°C (73°F) and -18°C (0°F), the average values were higher for the asphalt specimens (roof group I) at the lower temperature, whereas those for coal-tar pitch specimens (roof groups II, III, and IV) were lower at this temperature (table 5).

There was a significant difference between the average flexural strength values of the uncoated and coated asphalt specimens at the two temperatures. In both cases, average values of the coated specimens were less than those for the uncoated specimens. For the coal-tar pitch specimens, only one of the six comparisons indicated a significant difference in flexural strength. There was no trend as to whether the coated coal-tar pitch specimens had higher or lower average values.

6.5 Maximum Deflection

The values of maximum deflection (deflection at maximum flexural load) for individual specimens were obtained from the flexural strength tests and are presented in figure 4. The average values of maximum deflection (table 6) were lower at -18°C (0°F) than those at 23°C (73°F) for each of the four roof groups. It is noted that the average values of the flexural strength (table 5) of the coal-tar pitch specimens (roof groups II, III, and IV) were lower at -18°C (0°F) than those at 23°C (73°F). However, in the case of the asphalt specimens, the average values of flexural strength were higher at the lower temperature than those at 23°C (73°F).

For both temperatures, the average values of maximum deflection for the coated asphalt specimens were less than those of the uncoated asphalt specimens (table 6). These differences were statistically significant. However, no significant differences were found between the average values of uncoated and coated coal-tar pitch specimens at either temperature. The average values of maximum deflection of the coated coal-tar pitch specimens were higher than that of the uncoated specimens in 5 of the 6 cases compared.

6.6 Coefficient of Linear Thermal Expansion

Values of the coefficient of linear thermal expansion for individual specimens are plotted in figure 5 and average values for the uncoated and coated specimens for the roof groups are given in table 7. The scatter is greatest for the asphalt specimens tested at the higher temperature range. The average values for the asphalt specimens (roof group I) tested over the temperature range -18 to -34°C (0 to -30°F) were about twice those determined from -1 to -18°C (30 to 0°F). The temperature test range had little effect on the coal-tar pitch values.

In comparing the average values of the coefficient of linear thermal expansion of the uncoated and coated specimens for the four roof groups at the two temperature ranges, little or no difference was found (table 7). Only in the case of roof group II at the lower temperature range was the difference in average values significant. There was no consistent trend in whether or not the average values of the coated specimens were higher or lower than those for comparable uncoated specimens.

6.7 Thermal Shock Factor

Figure 6 presents values of thermal shock factor for individual membrane specimens. Values were higher for the asphalt specimens than for the coal-tar pitch specimens. The average values for the uncoated and coated specimens for the four roof groups showed no significant differences (table 8). No trend was found as to whether or not the average values of the coated specimens were higher or lower than those for comparable uncoated specimens.

7. DISCUSSION

Experience has shown that bituminous built-up membranes embrittle with age and show changes in performance properties such as a decrease in tensile strength and an increase in load-strain modulus (Mathey and Rossiter, 1977). "Resaturant"-type coatings are at times applied in attempts to restore flexibility and performance and to revitalize the roof (Karolefski, 1980). As previously indicated, the purpose of this investigation was to compare performance properties of comparable bituminous built-up membranes that had and had not been subjected to "resaturant"-type of coatings. If these types of coatings produce changes in mechanical properties of the membrane samples, it is believed that the changes should be measureable. Three "resaturant"-type coatings were included in the study. Because of the limited number of membrane samples and coatings in the study, the results are applicable only to the membranes tested. The results indicated that in the majority of cases comparing some mechanical properties of uncoated and comparable coated membrane specimens, statistically significant differences were not found. In addition, no trend was found as to whether or not the average value of a property for the coated specimens was higher or lower than that for comparable uncoated specimens.

Some possibilities may be considered as to whether the value of a particular performance property would be raised, lowered, or unchanged by the application of a "resaturant"-type of coating. For example, the tensile strength of a coated organic felt membrane might be expected to be higher than that of an uncoated membrane assuming that protection is provided against water penetration into the felts. Tensile strengths of organic felt membranes may be significantly reduced by moisture penetration (Laaly, 1977). In contrast, another possibility is that the tensile strength of a coated aged membrane might be expected to be lower than that of a comparable uncoated membrane assuming that the hardened bitumen had been softened by application of a coating. Tensile strengths of membranes embrittled by cold temperatures (-18°C or 0°F) are higher than comparable membranes tested at room temperature (Mathey and Cullen, 1974). With regard to load-strain modulus, an increase in this property generally occurs as membranes age and embrittle (Mathey and Rossiter, 1977). In this sense the modulus may be considered a measure of flexibility. It might be expected that if the coated membrane had increased flexibility, it would have a lower modulus than the comparable uncoated membrane. The results of this study showed no statistically significant difference between the tensile strengths and load-strain moduli of uncoated and comparable coated membrane specimens.

The flexural test was also considered to be a measure of membrane flexibility. The flexural strength of uncoated and coated membranes tested in the transverse direction may not be expected to differ appreciably. It has been reported that new flexible built-up bituminous membranes tested in the transverse direction at 23°C (73°F) had generally about the same flexural strengths as comparable membranes stiffened by cooling and tested at -18°C (0°F) (Mathey and Cullen, 1974). On the other hand the maximum deflections of the new flexible membranes were greater when tested in the transverse direction at 23°C (73°F) than at -18°C (0°F). In an analogous manner, it might be expected that if the coated membrane had increased flexibility compared to an uncoated membrane, then the coated membrane would exhibit greater maximum deflection. In the present study, only two of the eight comparisons of maximum deflection showed a significant difference in this property. However, in the two cases the average value of maximum deflection was less for the coated specimens than for the uncoated specimens. It is noted that the average values of flexural strength were also less for the coated than for the uncoated specimens.

The coefficient of linear thermal expansion of a membrane is partly dependent upon the coefficient of linear thermal expansion of the bitumen in the membrane. Bitumens embrittle with aging and their softening points increase. It has been indicated that lower softening point asphalts have a lower coefficient of linear thermal expansion in the temperature range of -18 to -34°C (0 to 30°F) than asphalts having a higher softening point (Bynoe, 1980). If this is the case, then membranes with lower softening point asphalts would have lower coefficients of linear thermal expansion than membranes with higher softening point asphalts. It might be expected that if the asphalt in a membrane has its softening point lowered because of a coating application, then the coefficient of linear thermal expansion of the membrane would be lowered. The results of this study showed no significant differences in the average values of coefficient of linear thermal expansion for uncoated and comparable coated asphalt membrane specimens and for five of the six comparisons of the uncoated and coated coal-tar pitch specimens (table 7).

The thermal shock factor is calculated (equation 1) from the tensile strength, load-strain modulus, and coefficient of linear thermal expansion. As discussed above, one possibility might be that coated specimens might have higher tensile strength and lower load-strain modulus and coefficient of linear thermal expansion. If this were the case, then coated specimens would have a higher thermal shock factor than uncoated specimens. In contrast, if coated specimens had lower tensile strength, load-strain modulus, and coefficient of thermal expansion than uncoated specimens, the thermal shock factor might be raised, lowered, or unchanged by the coating application. It was found that there was no significant difference between average values of thermal shock factor for uncoated and comparable coated membrane specimens.

8. SUMMARY AND CONCLUSIONS

This study compared some performance properties of weathered bituminous built-up roofing membranes which had and had not been treated with one of three proprietary "resaturant"-type coatings. Membrane samples removed from roofs of buildings were examined in the laboratory to observe their condition. The membrane performance properties determined for the uncoated and coated specimens were tensile strength, load-strain modulus, flexural strength, maximum deflection (flexure), coefficient of linear thermal expansion, and thermal shock factor. The average values of these properties for the uncoated and comparable coated membrane specimens were compared statistically. Possible changes in membrane property values which might be expected due to application of a "resaturant"-type coating were discussed.

From the laboratory examination of the condition of membrane samples it was found that damage to some areas of the top ply of felt of most of the coated coal-tar pitch membrane samples had occurred. This damage was attributed, in part, to the removal of the aggregate surfacing prior to application of the "resaturant"-type coating. The results of the laboratory tests were applicable only to the membranes tested since the number of membrane samples and coatings included in the study were limited. From the results, it was concluded that in general no statistically significant difference (0.05 significance level) in average values of the measured membrane performance properties existed between uncoated and comparable coated specimens.

9. ACKNOWLEDGMENTS

The preparation of this report was sponsored by the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. Dr. Robert Alumbaugh provided technical liaison between NCEL and NBS. The field and laboratory phases of the study were sponsored by the Energy Research and Development Administration, Mr. James Lampley made the arrangements for field sampling of the roofing membranes. Mr. John Fields provided assistance in taking the membrane samples from the roofs and background information such as roofing and coating ages. The laboratory tests of membrane performance properties were performed by Mr. Jessie Hairston, NBS.

Special appreciation and thanks are extended to Dr. James J. Filliben, Statistician, NBS, for his statistical analyses of the membrane property data and valuable comments and suggestions concerning this report.

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Table 1. Roofing Membrane Samples

Membrane Sample Number	Roof Group	Building Section Designation	Type of Bitumen	Age of Membrane years	Applied Coating	Age of Coating months
1	I	A	Asphalt	14	No	---
2		A	Asphalt	14	No	---
3		B	Asphalt	14	Yes	18
4		B	Asphalt	14	Yes	18
5	II	C	Coal-tar pitch	26	No	---
6		C	Coal-tar pitch	26	No	---
7		C	Coal-tar pitch	26	No	---
8		D	Coal-tar pitch	26	Yes	12
9		E	Coal-tar pitch	26	Yes	16
10		E	Coal-tar pitch	26	Yes	16
11		F	Coal-tar pitch	26	Yes	24
12		F	Coal-tar pitch	26	Yes	24
13	III	G	Coal-tar pitch	19	No	---
14		G	Coal-tar pitch	19	No	---
15		H	Coal-tar pitch	19	Yes	24
16		H	Coal-tar pitch	19	Yes	24
17	IV	I	Coal-tar pitch	26	No	---
18		I	Coal-tar pitch	26	No	---
19		J	Coal-tar pitch	26	Yes	29
20		J	Coal-tar pitch	26	Yes	29

Table 2. Visual Observations of Roofing Samples

Membrane Sample Number	Applied Coating	Roof Group	General Condition[a]	Pliability[b]	Number of Plies	Adhesion Between Plies[c]	Bitumen Interply Thickness[c]
1	No	I	Good	Pliable	4	Good	Normal
2	No		Good	Pliable	4	Good	Normal
3	Yes		Good	Pliable	4	Good	Normal
4	Yes		Good	Pliable	4	Good	Normal
5	No	II	Good	Brittle	4	Good	Thin
6	No		Good	Brittle	5[d]	Good	Thin
7	No		Good	Brittle	4	Good	Thin
8	Yes		Good[e]	Brittle	4[e]	Fair	Thin
9	Yes		Damaged	Brittle	4	Good	Thin
10	Yes		Damaged	Brittle	4	Fair	Thin
11	Yes		Damaged	Brittle	4	Good	Normal
12	Yes		Damaged	Brittle	4	Fair	Thin
13	No	III	Good	Brittle	4	Good	Normal
14	No		Good	Brittle	4	Good	Thin
15	Yes		Damaged	Brittle	4	Good	Normal
16	Yes		Good	Brittle	4	Good	Normal
17	No	IV	Good	Brittle	4	Good	Thin
18	No		Good	Brittle	4	Good	Normal
19	Yes		Damaged	Brittle	4	Good	Thin
20	Yes		Damaged	Brittle	4	Good	Thin

[a] The general condition of the samples was observed at room temperature prior to delamination. The membrane condition was considered to be good if typical defects were not observed, or were seen but limited to a relatively small area of the sample.

[b] Membrane strips were flexed manually at room temperature and subjectively judged as pliable or brittle.

[c] Observations were made subjectively from a delaminated strip cut from the membrane sample.

[d] The delaminated strip contained a ply of felt over 4 shingled plies.

[e] The delaminated strip contained a small patch over a split in the membrane.

Table 3. Statistical Summary of the Average Tensile Strengths for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated Coated	Tensile Strength[b] kN/m	lbf/in.	Pooled. Std. Deviation[c] kN/m	lbf/in.	Signif.[d]	Change in Property[e]
I	23°C	6	7.1	40.5	0.8	4.3	No	(-)
	(73°F)	6	6.2	35.5				
II		9	18.6	106.0	2.9	16.4	No	(-)
		15	17.3	98.9				
III		6	14.8	84.5	1.2	7.0	No	(-)
		6	14.6	83.2				
IV		6	16.4	93.5	2.3	13.3	No	(+)
		6	18.0	103.0				
I	-18°C	6	24.3	139.0	3.2	18.1	No	(-)
	(0°F)	6	21.4	122.0				
II		9	32.7	187.0	5.0	28.5	No	(+)
		15	36.8	210.0				
III		6	34.9	199.0	6.0	34.1	No	(+)
		6	35.7	204.0				
IV		6	41.7	238.0	11.5	65.8	No	(-)
		6	32.6	186.0				

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the tensile strengths of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average tensile strengths for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

Table 4. Statistical Summary of the Average Load-Strain Modulus for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated / Coated	Load-Strain Mod.[b] MN/m	Load-Strain Mod.[b] lbf/in. x 10^4	Pooled Std. Deviation[c] MN/m	Pooled Std. Deviation[c] lbf/in. x 10^4	Signif.[d]	Change in Property[e]
I	23°C (73°F)	6	0.88	0.50	0.33	0.19	No	None
		6	0.88	0.50				
II		9	8.6	4.9	8.4	4.8	No	(-)
		14	2.3	1.3				
III		6	2.1	1.2	0.70	0.4	No	(-)
		6	1.9	1.1				
IV		6	2.6	1.5	1.1	0.6	No	(-)
		6	2.3	1.3				
I	-18°C (0°F)	6	4.0	2.3	5.3	0.3	No	(-)
		6	3.3	1.9				
II		9	40.1	22.9	87.0	49.7	No	(+)
		15	70.6	40.3				
III		6	21.9	12.5	6.5	3.7	No	(+)
		6	26.6	15.2				
IV		6	45.9	26.2	52.4	29.9	No	(+)
		6	65.8	37.6				

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the load-strain moduli of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average load-strain modulus for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

Table 5. Statistical Summary of the Average Flexural Strengths for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated Coated	Flexural Strength[b] kN/m	lbf/in.	Pooled Std. Deviation[c] kN/m	lbf/in.	Signif.[d]	Change in Property[e]
I	23°C (73°F)	6 6	2.7 1.7	15.3 9.5	0.7	3.8	Yes	(-)
II		8 15	9.5 9.3	54.0 52.9	3.3	18.8	No	(-)
III		6 6	14.7 15.7	84.2 89.8	2.0	11.6	No	(+)
IV		6 6	14.4 9.9	82.5 56.3	2.5	14.3	Yes	(-)
I	-18°C (0°F)	6 6	5.2 3.9	29.8 22.5	1.0	5.7	Yes	(-)
II		9 15	3.4 3.4	19.6 19.3	0.6	3.4	No	(-)
III		6 6	3.6 3.9	20.3 22.3	0.7	3.9	No	(+)
IV		6 6	4.9 4.5	27.7 25.8	1.7	9.5	No	(-)

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the flexural strengths of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average flexural strength for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

Table 6. Statistical Summary of the Average Maximum Deflections for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated Coated	Maximum Deflection[b] mm	in.	Pooled Std. Deviation[c] mm	in.	Signif.[d]	Change in Property[e]
I	23°C	6	19.1	0.75	2.8	0.11	Yes	(-)
	(73°F)	5	12.4	0.49				
II		8	20.8	0.82	5.8	0.23	No	(+)
		15	24.4	0.96				
III		6	29.0	1.14	3.6	0.14	No	(+)
		6	33.0	1.30				
IV		6	28.2	1.11	4.3	0.17	No	(-)
		6	23.6	0.93				
I	-18°C	6	13.2	0.52	1.0	0.04	Yes	(-)
	(0°F)	6	11.7	0.46				
II		9	4.6	0.18	1.0	0.04	No	(+)
		15	4.8	0.19				
III		6	4.8	0.19	1.3	0.05	No	(+)
		6	5.8	0.23				
IV		6	4.3	0.17	1.3	0.05	No	(+)
		6	4.6	0.18				

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the maximum deflections of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average maximum deflection for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

Table 7. Statistical Summary of the Average Coefficients of Linear Thermal Expansion for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated Coated	CLTE[b] °C^{-1}x10^{-6}	CLTE[b] °F^{-1}x10^{-6}	Pooled Std. Deviation[c] °C^{-1}x10^{-6}	Pooled Std. Deviation[c] °F^{-1}x10^{-6}	Signif.[d]	Change in Property[e]
I	-1 to -18°C	6	26.6	14.8	20.0	11.1	No	(+)
	(30 to 0°F)	6	28.6	15.9				
II		9	49.0	27.2	5.8	3.2	No	(+)
		15	52.7	29.3				
III		6	52.0	28.9	5.6	3.1	No	(-)
		6	51.8	28.8				
IV		6	49.0	27.2	5.2	2.9	No	(-)
		6	48.4	26.9				
I	-18 to -34°C	6	53.5	29.7	12.1	6.7	No	None
	(0 to -30°F)	6	53.5	29.7				
II		9	48.8	27.1	3.6	2.0	Yes	(-)
		15	45.0	25.0				
III		6	49.7	27.6	5.4	3.0	No	(+)
		6	53.1	29.5				
IV		6	46.8	26.0	7.6	4.2	No	(+)
		6	49.1	27.3				

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the coefficients of linear thermal expansion of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average coefficient of linear thermal expansion for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

Table 8. Statistical Summary of the Average Thermal Shock Factors for the Membrane Specimens as Separated into the Four Roof Groups

Roof Group	Test Temp.	No. of Specimens[a] Uncoated Coated	TSF[b] °C	TSF[b] °F	Pooled Std. Deviation[c] °C	Pooled Std. Deviation[c] °F	Signif.[d]	Change in Property[e]
I	-18°C	6	119	214	43.7	78.7	No	(+)
	(0°F)	6	127	229				
II		9	21.2	38.2	14.1	25.4	No	(+)
		15	28.3	50.9				
III		6	33.4	60.2	7.4	13.4	No	(-)
		6	26.8	48.3				
IV		6	23.3	42.0	13.0	23.4	No	(-)
		6	23.2	41.7				

[a] For each roof group, the upper value gives the number of uncoated specimens and the lower value gives the number of coated specimens

[b] For each roof group, the values of the upper and lower lines are the average values of the thermal shock factors of the uncoated and coated specimens, respectively.

[c] Pooled Std. Deviation indicates the residual standard deviation of the average thermal shock factor for all specimens tested within a roof group.

[d] Signif. means significance at the 0.05 significance level and pertains to whether the results of the t-test indicated a significant difference between the average values of the uncoated and coated specimens.

[e] A (+) sign and a (-) sign indicate that the average value of the coated specimens was greater than or less than that of the uncoated specimens, respectively.

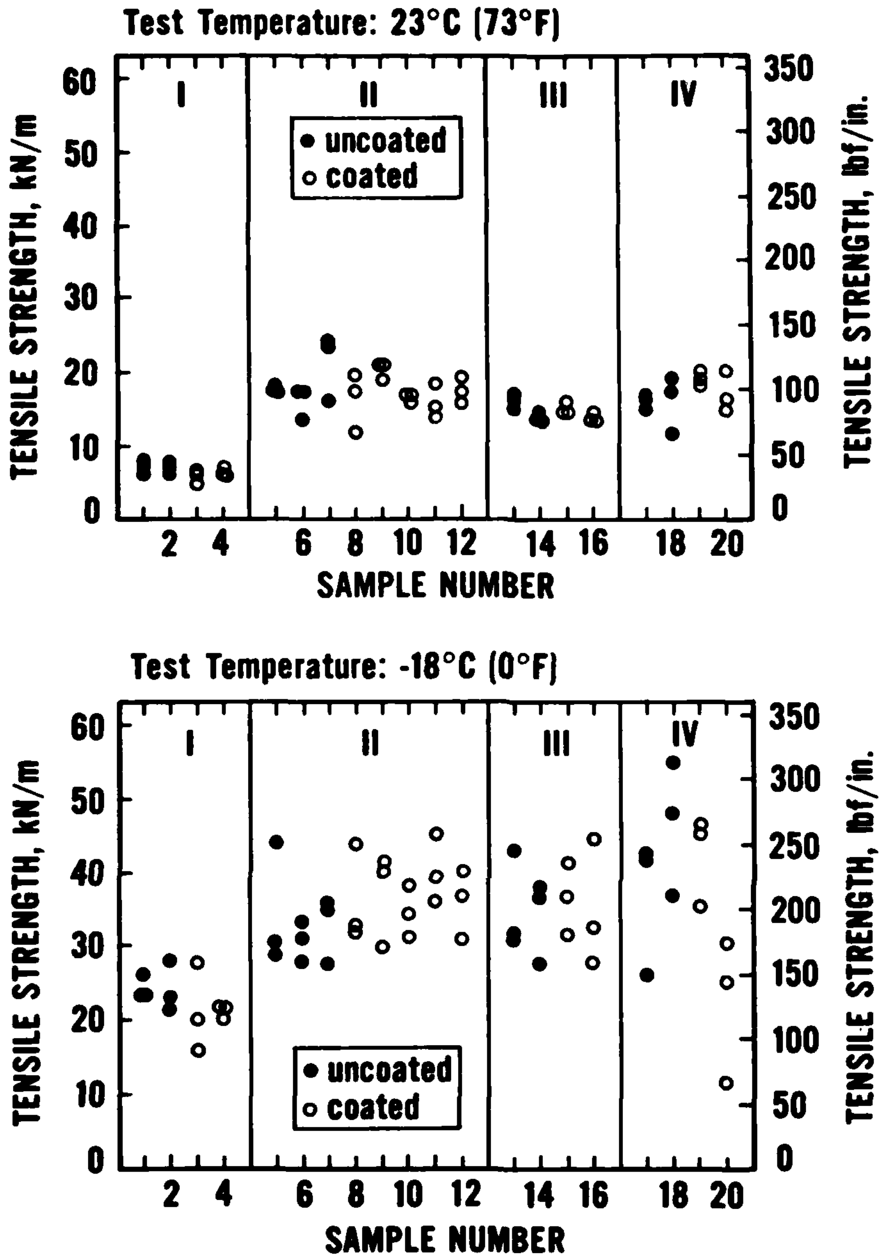


Figure 1. Tensile strengths of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV

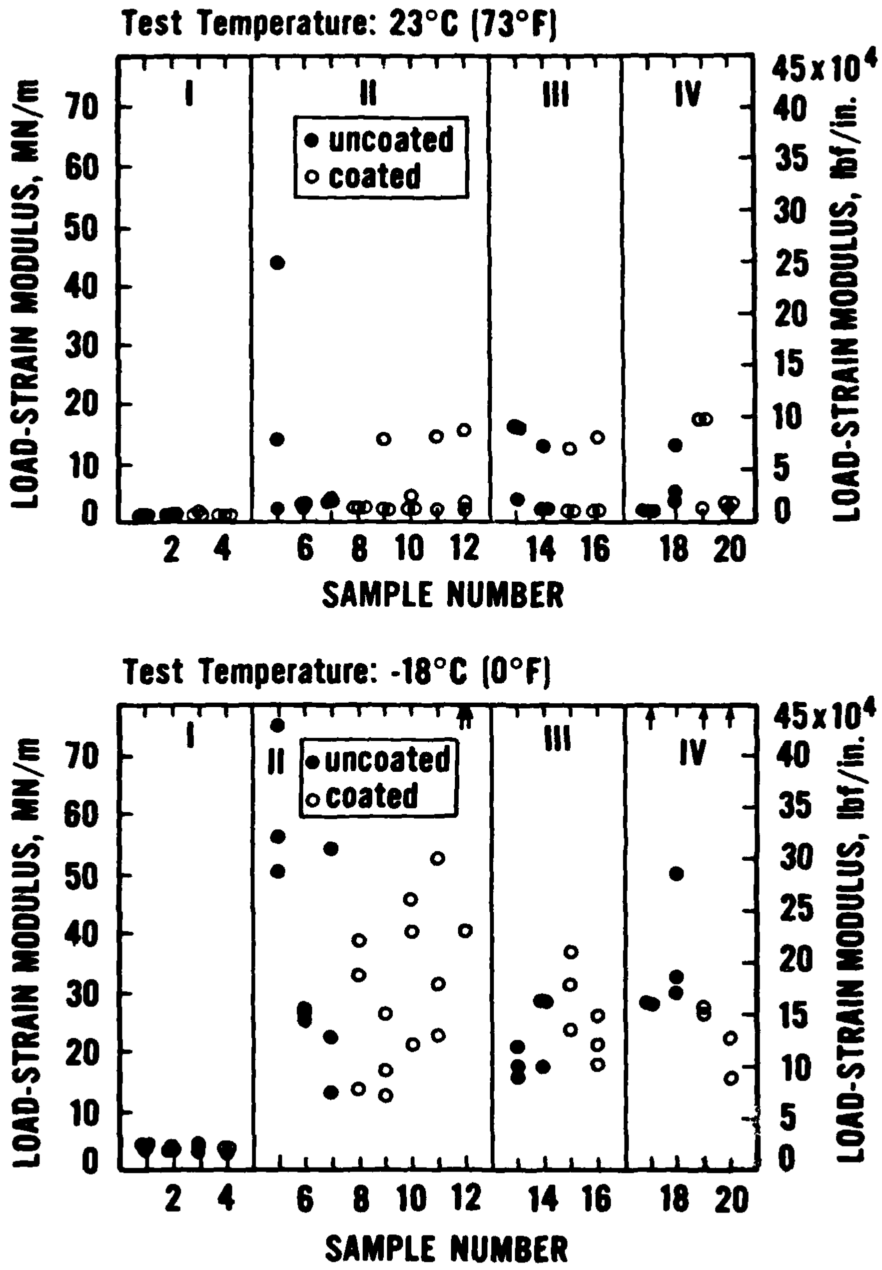


Figure 2. Load-strain modulus of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV

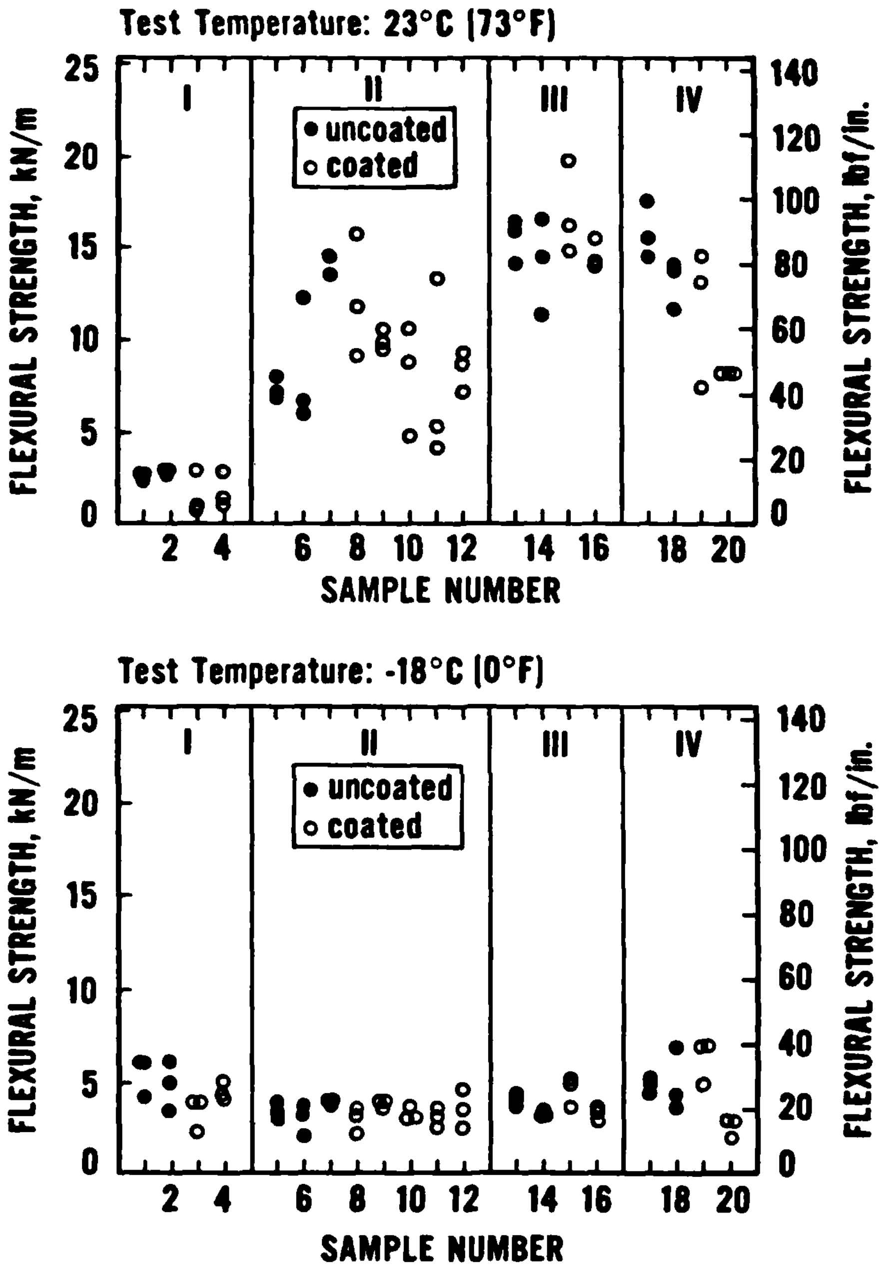
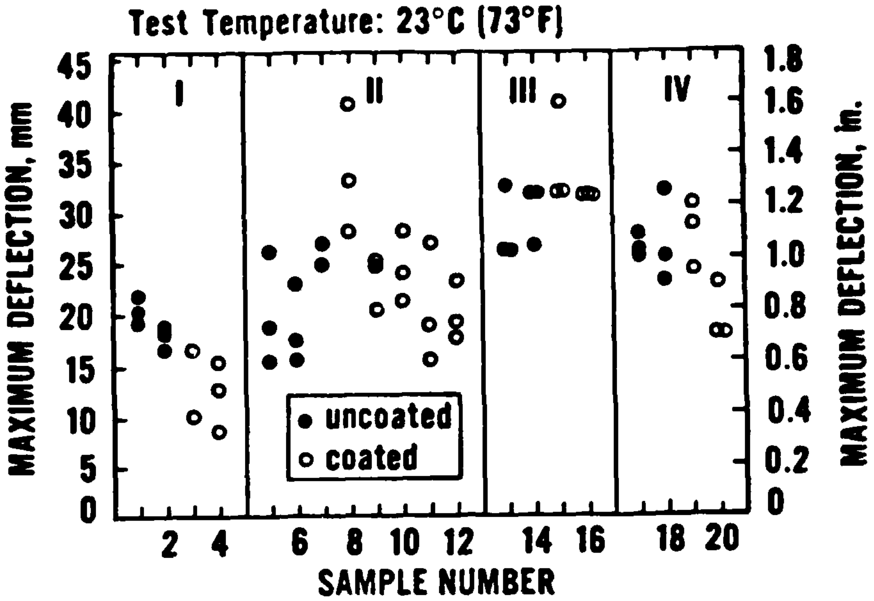


Figure 3. Flexural strengths of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV



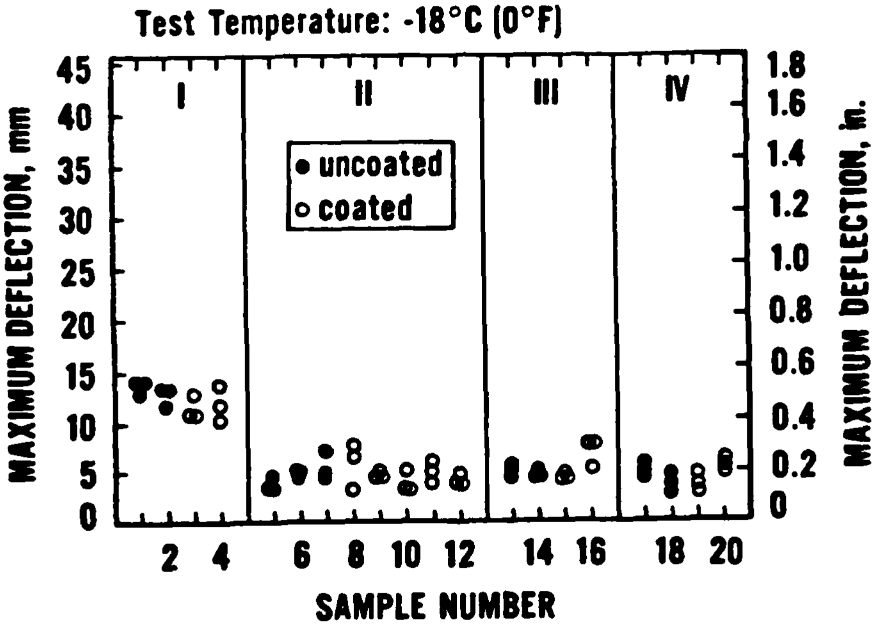


Figure 4. Maximum deflection of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV

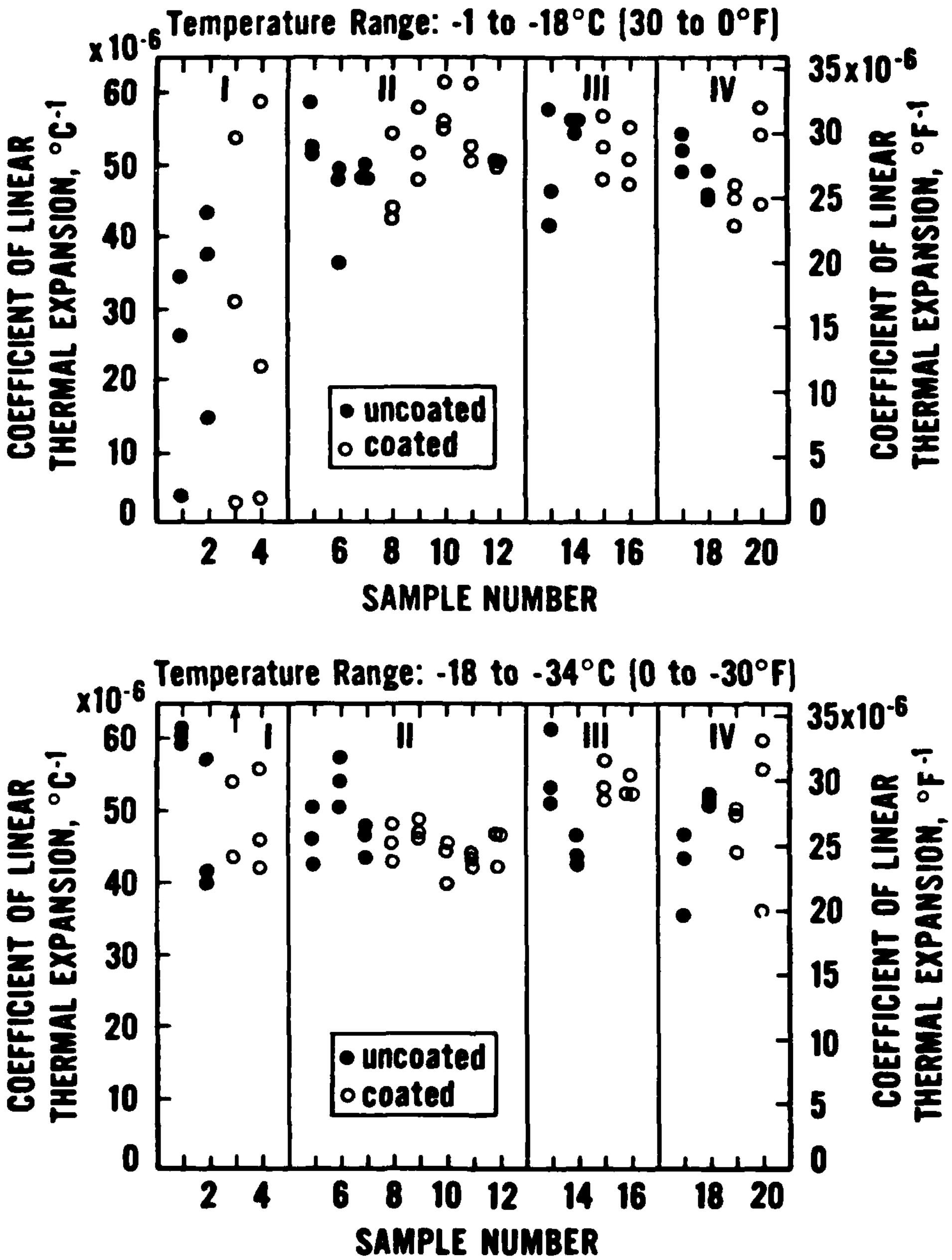


Figure 5. Coefficients of linear thermal expansion of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV

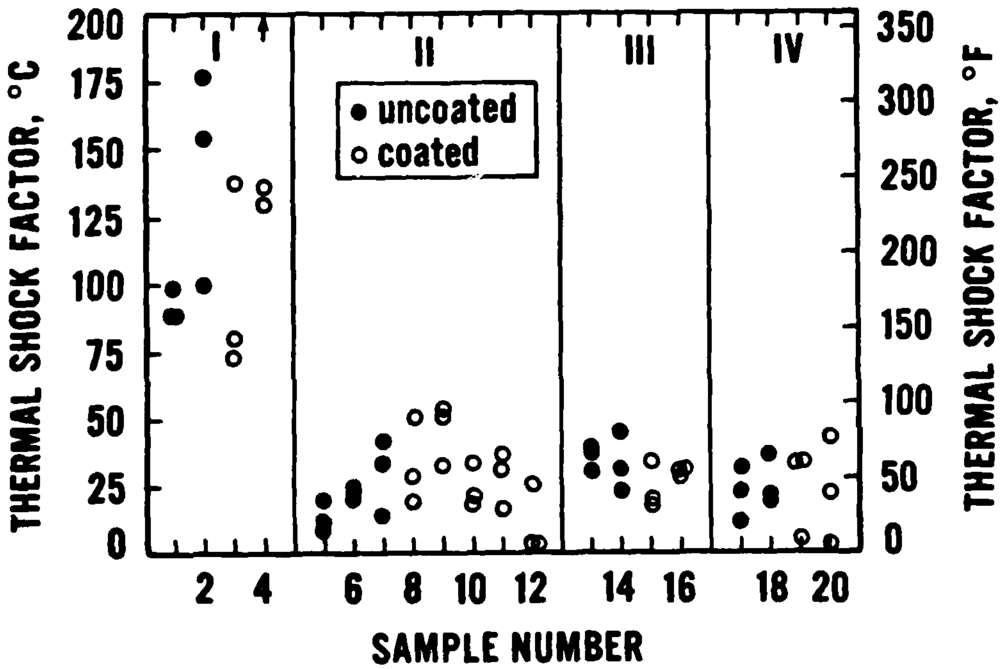


Figure 6. Thermal shock factors of the uncoated and coated membrane samples tested at 23 and -18°C (73 and 0°F) in the transverse direction of the membrane felt. Data are presented according to the roof groups I, II, III, and IV

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NAVORDSTA MDS-25, Mfg Tech Dept Louisville, KY; PWO, Louisville KY
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NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
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NAVSECGRUCOM Code G43, Washington DC
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NAVSHIPREPFAC SCE Subic Bay; SCE, Guam; SCE, Yokosuka Japan
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NAVSTA CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY; Code 16P, Keflavik, Iceland; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Control Div., Adak; Maintenance Div., Rota, Spain; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWD - Engr. Div, Keflavik; PWD, Utilities Div., Guantanamo Bay Cuba; PWO, Adak, AK; PWO, Brooklyn NY; PWO, Guantanamo Bay Cuba; PWO, Keflavik Iceland; PWO, Mayport FL; SCE Guam; SCE, Pearl Harbor HI; SCE San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. Rota Spain
NAVSUBASE Code 23 (Slowey) Bremerton, WA; PWO
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NAVSUPPO Security Offr, Sardinia
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NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO Colts Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach CA
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NAVY PAO CENTER Directory, San Diego, CA
NCBU 405 OIC, San Diego, CA
NCTC Const. Elec. School, Port Hueneme, CA
NCBC CO, Gulfport MS; Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 400, Gulfport MS; Code 430 (PW Engrng) Gulfport, MS; PWO (Code 80) Port Hueneme, CA; PWO (Code 82), Port Hueneme CA; PWO, Gulfport, MS; Port Hueneme CA
NCBU 411 OIC, Norfolk VA
NCBU 416 OIC, Alameda CA
NCR 20, Code R31 Gulfport, MS; 20, Code R70; 20, Commander; 30, Guam, Commander
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NSC Code 54.1 Norfolk, VA; Code 700 Norfolk, VA; Code 703 (J. Gammon) Pearl Harbor, HI; SCE (Code

70), Oakland CA; SCE Norfolk, VA; SCE Pearl Harbor, HI; SCE, Charleston, SC
NSD PWD - Engr Div, Guam; SCE, Subic Bay, R.P.
NTC OICC, CBU-401, Great Lakes IL; SCE, San Diego CA
NTIS Lehmann, Springfield, VA
NUSC Code 3009 (CDR O. Porter) Newport, RI; Code 4123 New London, CT; Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De La Cruz), New London CT; PWO AUTEC West Palm Bch Det, West Palm Beach, FL; PWO New London, CT; PWO Newport, RI; SB322 (Tucker), Newport RI
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ONR Central Regional Office, Boston, MA; Code 485 (Silva) Arlington, VA; Code 700F Arlington VA; LCDR Williams, Boston, MA; Nelson, Arlington, VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA
PWC ACE Office Norfolk, VA; CO Norfolk, VA; CO Yokosuka, Japan; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; CO, San Diego CA; CO, Subic Bay, R.P.; Code 10, Great Lakes, IL; Code 101, San Diego, CA; Code 105 Oakland, CA; Code 105, Oakland, CA; Code 110, Oakland, CA; Code 120, Oakland CA; Code 120, San Diego CA; Code 128, Guam; Code 154 (Library), Great Lakes, IL; Code 200 (H. Koubenec), Great Lakes IL; Code 200, Great Lakes IL; Code 200, Guam; Code 240, Subic Bay, R.P.; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 420, Pensacola, FL; Code 420, San Diego, CA; Code 424, Norfolk, VA; Code 500, Great Lakes, IL; Code 500, Oakland, CA; Code 500, San Diego, CA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; Code 800, San Diego, CA; Library, Code 120C, San Diego, CA; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Maint. Control Dept (R. Fujii) Pearl Harbor, HI; Maint. Control Dept. Oakland CA; Production Officer, Norfolk, VA; Utilities Officer, Guam
SPCC PWD - Maint. Control Div, Mechanicsburg, PA; PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA
TVA Solar Group, Arnold, Knoxville, TN
UCT ONE OIC, Norfolk, VA
UCT TWO OIC, Port Hueneme CA
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